PARALLEL NON-ITERATIVE METHOD OF DETERMINING AND CORRECTING IMAGE SKEW

Background of the Invention

The present invention relates to the art of image processing It finds particular application in conjunction with determining and correcting image skew of a digital image, and will be described with particular reference thereto. It is to be appreciated, however, that the invention also finds application in conjunction with determining image skew in images acquired using a variety of image acquisition and output devices, such as scanners, and xerographic copiers and printers

Lines of text within images of scanned documents are typically brought into nearly upright orientation within a rotation of a multiple of 90 degrees The multiple describes the orientation of the image. For example, if the required rotation orientation is 0 or 180 degrees, the image is in portrait mode, while a required rotation orientation of 90 or 270 degrees indicates that the image is in landscape mode After such rotation, the text lines, if they exist, typically have a small amount of skew, generally less than 5 degrees with respect to the raster lines

In many image processing applications, it is desirable to determine and correct skew of a document image. For example, many text recognition systems, such as optical character recognition (OCR) systems, fail if presented with text oriented with a skew of more than a few degrees, not to mention if the text is oriented sideways or upside-down. In addition, it is easier to identify text lines and text columns if the image skew is known or the image is deskewed.

A variety of methods for determining image skew have been proposed One approach involves using bounding boxes of connected components to estimate image skew. The coordinates of a token point, on the bottom center of the bounding box, are selected, and a function S_{tokens} of skew angle is computed from these coordinates. Specifically, the function $S_{tokens}(\theta)$ is the sum of squares of the number of such points computed along a set of lines with the angle θ to the raster direction A vertical shear is simulated on the set of points and the sums over the points with the same y-coordinate are determined Aside from a constant (independent of θ), the function S_{tokens} is the variance of the number of tokens on a line, as a function of

angle. This variance is a maximum in the direction where the tokens for each text line fall near the same line.

Another method for determining skew traverses straight lines of the image at a set of angles relative to the raster direction A function $S_\delta(\theta)$ is computed that has a maximum value when the scan direction θ is along the text lines. Unlike the approach described above, which computes tokens from connected components, this method uses every pixel in the image. The function $S_\delta(\theta)$ is similar to the function $S_{tokens}(\theta)$ in the sense that an angle θ is chosen and pixel sums are found along lines in the image at this angle. However, instead of squaring the sum of tokens, the second method squares the difference between sums of ON pixels on adjacent lines, and the function $S_\delta(\theta)$ is found by summing over all lines. The function $S_\delta(\theta)$ is, aside from a constant, the variance in the difference between pixel sums on adjacent lines at the angle θ

The deskew methods described above, along with other deskew methods, use an iterative estimation approach based upon the method disclosed by Baird in U.S. Patent No. 5,001,766. The Baird method requires a local copy of the image to be stored, thus obviating pipeline processing. Further, the iterative nature of Baird's method eliminates the possibility of parallel processing Therefore, the speed at which an image may be deskewed is necessarily limited Also, such iterative approaches may lead to local maximums instead of the correct global maximum and, therefore, report false angles in complex documents.

The present invention contemplates a new and improved method and apparatus for determining and correcting image skew, which overcomes the above-referenced problems and others.

Summary of the Invention

In accordance with one aspect of the present invention, a method of determining skew of an image in an optical scanning device includes optically scanning a document to produce scanned image data, which includes a plurality of scan lines having ON and OFF pixels. The image data is sampled on at least one scan line along a fast scan direction and a slow scan direction for one document rotation angle in order to determine a number of ON pixels on each scan line A fast scan second order moment data set is calculated based on the number of ON pixels on the

at least one scan line along the fast scan direction for a plurality of document rotation angles. A slow scan second order moment data set is calculated based on the number of ON pixels on the at least one scan line along the slow scan direction for a plurality of document rotation angles. A first skew angle estimate is calculated from the fast

5   scan second order moment data set and a second skew angle estimate is calculated from the slow scan second order moment data set. The validity of the fast scan and slow scan second order moment data sets is determined and the calculated skew angle estimates corresponding to valid second order moment data sets are combined to yield a resultant skew angle.

10   In accordance with a more limited aspect of the present invention, the method includes reading a pixel at a first document rotation angle where the pixel is located on a first scan line. Without rotating the document, the pixel is projected onto other scan lines, which correspond to a plurality of predetermined document rotation angles. If the pixel is an ON pixel, a plurality of counters are simultaneously updated

15   where each counter corresponds to one of the plurality of predetermined document rotation angles.

              In accordance with a more limited aspect of the present invention, the fast scan second order moment data set is calculated by an equation of the form:

$$\sum_{i=1}^{N} (n_i)^2$$

20   where N is the number of scan lines along the fast scan direction, n is the number of ON pixels in a scan line, and i is a counter for the scan lines along the fast scan direction.

              In accordance with a more limited aspect of the present invention, the slow scan second order moment data set is calculated by an equation of the form

$$\sum_{j=1}^{M} (m_j)^2$$

25   where M is the number of scan columns along the slow scan direction, m is the number of ON pixels in a scan column, and j is a counter for the scan columns along the slow scan direction.

              In accordance with a more limited aspect of the present invention, the

30   fast scan and slow scan second order moment data sets are locally fit near a measured maximum with an equation of the form

$$S_\alpha = S_{\alpha max} - k \mid \alpha - \alpha_{max} \mid$$

where $S_{\alpha max}$ is a maximum second order moment, and α_{max} is the document rotation

angle at which $S_{\alpha max}$ occurs.

In accordance with a more limited aspect of the present invention,

5   second order moment data sets which do not have a single dominant peak are

invalidated In addition, second order moment data sets not having a dominant peak

which corresponds to a strictly decreasing function are invalidated

In accordance with a more limited aspect of the present invention, a

first quality factor related to the strength of a single dominant peak is calculated The

10   first quality factor is compared to a first predetermined threshold. A second quality

factor related to the slope of the single dominant peak is calculated and compared to a

second predetermined threshold.

In accordance with a more limited aspect of the present invention, the

step of combining skew angle estimates corresponding to valid data sets includes

15   determining how many second order moment data sets are valid If no valid second

order moment data set exists, failure is declared and no resultant skew angle is

reported. If one valid second order moment data set exists, the skew angle estimate

corresponding to the valid second order moment data set is reported If both the fast

scan and slow scan second order moment data sets are valid, a difference between the

20   first quality factors for the fast scan and slow scan second order moments are

calculated The quality factor difference is compared to a difference threshold If the

quality factor difference is greater than the difference threshold, the skew angle

estimate corresponding to the second order moment data set having a larger first

quality factor is reported. If the quality factor difference is less than the difference

25   threshold, a skew angle difference between the first and second skew angle estimates

is calculated The skew angle difference is compared to a third predetermined

threshold If the skew angle difference is greater than the third predetermined

threshold, the smaller skew angle estimate is reported If the skew angle difference is

less than the third predetermined threshold, the first and second skew angle estimates

30   are averaged to yield a resultant skew angle.

In accordance with another aspect of the present invention, a method of

determining a document skew angle includes scanning a document to produce image

data made up of scan lines having ON and OFF pixels A first independent skew

angle estimate is determined based on a number of ON pixels on a plurality of scan

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lines along a fast scan direction A second independent skew angle estimate is determined based on a number of ON pixels on a plurality of scanned columns along a slow scan direction. The first and second independent skew angle estimates are merged to yield the document skew angle.

5   In accordance with a more limited aspect of the present invention, the determining steps include, without rotating the document, simultaneously calculating a second order moment of ON pixels on the scan lines along the fast scan direction at a plurality of document rotation angles Further, without rotating the document, a second order moment of ON pixels on the scan columns along the slow scan direction

10   is simultaneously calculated at a plurality of document rotation angles.

          In accordance with another aspect of the present invention, a xerographic apparatus programmed to determine image skew of a scanned document includes an imaging platen and means for scanning successive scan lines of the document, where the scan lines have ON pixels and OFF pixels A memory stores

15   scanned image data representing a skewed image Reading means are employed for reading a pixel at a first document rotation angle, where the pixel is located on a first scan line. Projection means project the pixel onto other scan lines corresponding to a plurality of predetermined document rotation angles. A plurality of pixel counters simultaneously count a number of ON pixels along a plurality of scan lines and

20   columns A skew angle processor computes first and second independent skew angle estimates based on the number of ON pixels along the plurality of scan lines and columns The skew angle processor merges the first and second skew angle estimates to yield a resultant skew angle. An image processor corrects the skewed image in accordance with the resultant skew angle. Transferring means transfer an image

25   charge pattern onto a photoreceptor. At least one developing station develops the charge pattern and at least one fuser fixes a developed image onto a physical media

          One advantage of the present invention resides in efficient skew angle determination employing parallel processing

          Another advantage of the present invention resides in the use of two

30   independent skew angle estimations.

          Another advantage of the present invention is resides in determining skew angle without storing a local copy of the image

Yet another advantage of the present invention resides in simultaneous calculation of a second order moment at multiple sampling angles through one read of the image data.

Still other benefits and advantages of the present invention will become apparent to those skilled in the art upon a reading and understanding of the preferred embodiments.

Brief Description of the Drawings

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps The drawings are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 is a functional block diagram of an imaging apparatus suitable to practice an embodiment of the present invention,

FIGURE 2 is a flow chart illustrating a method of determining image skew in accordance with the present invention;

FIGURE 3 is a flow chart illustrating a method of simultaneously sampling pixel data at a plurality of document rotation angles in accordance with the present invention;

FIGURE 4 is a diagrammatic illustration of the method provided in FIGURE 3;

FIGURE 5 is a flow chart illustrating a method of validating a second order moment data set in accordance with the present invention, and

FIGURE 6 is a flow chart illustrating a method of combining skew angle estimates from valid data sets in accordance with the present invention

Detailed Description of the Preferred Embodiments

With reference to FIGURE 1, an imaging apparatus is illustrated which determines and corrects image skew in a scanned document **12** Image skew refers to rotational error between the dominant orientation of lines of printed objects, such as characters, within a document and a reference line observed by a reader or scanner as being zero rotational error A scanner **16** scans the document **12** in a conventional manner, producing electrical scanned image data, a copy of which is stored in an image data memory **20**. The scanned image data is represented as a two-dimensional data set of pixel information. The data set consists of line data in one dimension and column data in the other dimension. Due to the rastering motion of the particular

input device in the scanner, a line of data is acquired relatively quickly. In contrast, each column of data, which is perpendicular to the line of data, is acquired relatively slowly. Accordingly, the axis of the image or acquired data set that is parallel to each line of data is referred to as the fast scan direction. Analogously, the axis of the image or acquired data set that is parallel to each column of data is referred to as the slow scan direction.

The digitized scan lines and columns of data are comprised of individual pixels considered to be an ON pixel or an OFF pixel. Pixels are defined to be ON if they are black and OFF if they are white. It is to be appreciated that the designation of black as ON and white as OFF reflects the fact that most documents of interest have a black foreground and a white background. However, it is to be appreciated that the present invention is equally applicable to negative images as well.

As is explained more fully below, through one "read" of the image, the image data is sampled at a plurality of predetermined document rotation angles to determine the number of ON pixels per sampled scan line. More particularly, the second order moment of the number of ON pixels is calculated for various document rotation angles. The second order moment, which is sometimes referred to as the variance, is the mean value of the sum of the square of the number of ON pixels on each scan line for a given document rotation angle. The second order moment is calculated as a function of document rotation angle for scan lines and columns along both the fast scan and slow scan directions, yielding fast scan and slow scan second order moment data sets. From the fast scan and slow scan second order moment data sets, first and second skew angle estimates are calculated, compared, and combined to yield a resultant skew angle.

Rather than computing the second order moment for a given document rotation angle, rotating the image, and repeating the process, the second order moments for several document rotation angles are simultaneously calculated and updated on a pixel-by-pixel basis. For a given document rotation angle, as each pixel is read, i.e., determined to be ON or OFF, that pixel's location is calculated for all predetermined document rotation angles simultaneously by a plurality of pixel counters **24** and the corresponding row and column sums of ON pixels are updated. In other words, rather than rotating the image, counting the ON pixels, and calculating the complete second order moment at that particular document rotation angle, as each pixel is read, its location is calculated simultaneously for each document rotation

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angle to be sampled as if it were rotated and added in at that time Therefore, through one read of the image, the row and column pixel sums at each of the predetermined document rotation angles are calculated simultaneously The plurality of pixel counters **24**, which facilitate parallel processing, transfer second order moment data sets for both the fast scan and slow scan directions to a skew angle processor **30**, which processes the second order moment data sets to yield a resultant image skew angle.

An image processor **38**, containing a memory **40**, receives the calculated skew angle estimate and applies it to the scanned image data received from the image data memory **20**. The image processor **38** corrects the skew error present in the image in accordance with the resultant skew angle estimate received from the skew angle processor **30**. Skew correction involves rotating the original image stored in the image data memory **20** by the negative of the skew angle determined by the skew angle processor so as to deskew the image. Such means for rotating the image are well known, and include, for small angles of rotation (less than 5 degrees), applying two orthogonal shears For larger skew angles, rotation can be approximated by three shears, with the first and third shear of equal magnitude in the horizontal direction and the second larger shear in the vertical direction

The deskewed digital image representation is output to one of a plurality of image output devices, such as a xerographic printer **50** In this embodiment, the digital image representation is transferred to an image processing controller **52** The controller communicates the image data to the remainder of the printing machine, including an illuminator **54**, which transfers a physical image onto a photosensitive surface, at least one developer station **56**, and a fuser station **58**, which produces a hard copy **60** of the scanned image. Alternatively, the digital image representation is output to a computer or network

More particularly, in the practice of conventional xerography, an electrostatic latent image is formed on a xerographic surface by first uniformly charging a charge retentive surface, such as a photoreceptor The charged area is selectively dissipated in accordance with a pattern of activating radiation corresponding to original images The selective dissipation of the charge leaves a latent charge pattern on the imaging surface corresponding to areas not exposed to radiation.

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The charge pattern is made visible by developing it with toner by passing the photoreceptor past at least one developer station **56**. The toner is generally a black or colored powder, which adheres to the charge pattern by electrostatic attraction. The developed image is then fixed to the imaging surface or is transferred to a receiving substrate, such as plain paper or other physical media, to which it is fixed by suitable fusing techniques.

With reference to FIGURE 2 and continuing reference to FIGURE 1, a method of determining image skew of a scanned document is illustrated. A document is scanned **200** in a conventional manner, producing scanned image data. Optionally, the image data is reduced **210** so as to accelerate the process. Reduction is a scale operation characterized by a scale factor A and a threshold level B. Reduction with scale=A entails dividing the source image into AxA squares of pixels, mapping each such square in the source image to a single pixel on the destination image. The value for the destination image pixel is determined by the threshold level B, which is a number between 1 and A^2. If the number of ON pixels in the pixel square is greater than or equal to B, the destination pixel is considered to be ON, otherwise it is considered to be OFF. The advantage of performing the operation at a reduced scale is that the time to perform each operation, such as counting, varies with the square of the reduction factor. For example, a reduction by a factor of 4 reduces the computation time by a factor of 16.

It is to be appreciated that while a conventional reduction step is discussed above, other forms of reduction may be employed, such as sub-sampling. Sub-sampling is an operation wherein the source image is subdivided into smaller, typically square elements. Each element in the source image is mapped to a smaller element in the destination image. The pixel values for each destination image element are defined by a selected subset of the pixels in the source image element. Typically, sub-sampling entails mapping to single pixels, with the destination pixel value being the same as a selected pixel from the source image element.

Scan lines and columns of image data are sampled **220** along two directions, i e , the fast scan and slow scan directions, at a first predetermined document rotation angle in order to determined the number of ON pixels per sampled scan line or column. More particularly, through one read of the image, the image data is sampled simultaneously at a plurality of predetermined document rotation angles to determine the number of ON pixels per sampled scan line or column. With reference

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to FIGURE 3 and continuing reference to FIGURE 2, for a given document rotation angle, a pixel is sampled or read **300**, that is, determined to be either ON or OFF Rather than sum the number of ON pixels at a particular document rotation angle, calculate the second order moment at that particular document rotation angle, and rotate the image to the next predetermined document rotation angle, the location of the pixel being sampled is projected for a plurality of predetermined document rotation angles. In other words, for a sampling scheme in which pixels are sampled along scan lines and columns at D predetermined document rotation angles, the modified location of the particular pixel at the D document rotation angles is calculated in parallel by the plurality of pixel counters or processors

For example, with reference to FIGURE 4 and continuing reference to FIGURES 2 and 3, a document **400** having a plurality of scan lines is illustrated For example, at a given document rotation angle of zero miliradians, a particular pixel **410,** which is determined to be ON, is located at a certain x value on scan line 1200 **420**. Pixel **410** is counted and added up along scan line 1200 **420** However, for a different document rotation angle, e.g., $\alpha = 1$ miliradian, the pixel at position **410** would move to position **430** on scan line 1100. It is to be appreciated that projected pixel position **430** is calculated to fall on scan line 1100 by the formula $\Delta y = x\alpha$. Artisans will appreciate that this relationship holds true because $\tan \alpha \approx \alpha$ for small alphas. Therefore, as each pixel is read for an initial document rotation angle, the scan line onto which it would project is calculated and the subsequent pixel count is updated for 20 or 30 predetermined document rotation angles to be sampled as the pixel is read. In other words, through one read of the image, the pixel sums are calculated simultaneously for all predetermined document rotation angles

Referring back to FIGURE 3, based on the projected pixel locations for each document rotation angle, the corresponding row and column sums are updated **320** simultaneously. As is explained more fully below, the second order moments of the ON pixels are calculated for each predetermined document rotation angle based on the updated row and column sums.

Referring back to FIGURE 2, a second order moment data set is calculated **230** for scan lines along the fast scan direction In other words, the second order moment data set includes calculated second order moments as a function of document rotation angle. The second order moment is the mean value of the sum of

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the square of the number of ON pixels on each scan line for a given document rotation angle More particularly, the second order moment is calculated by an equation of the form

$$\sum_{i=1}^{N} (n_i)^2 \qquad (1)$$

where N is the number of scan lines along the fast scan direction, n is the number of ON pixels in a scan line; and i is a counter for the scan lines along the fast scan direction. Stated differently, for a given document rotation angle, the second order moment is calculated by summing the number of ON pixels across each scan line or row, squaring that sum, and summing over all of the scan lines While the second order moment is the preferred metric for determining skew angle, it is to be appreciated that other metrics may be employed, such as the square of the difference between sums of ON pixels on adjacent scan lines or the variance

The same process is employed to calculate a second order moment data set along the slow scan direction **235** by performing the above-described operation, only summing along columns rather than rows. In other words, in order to calculate the second order moment data set along the slow scan direction, the number of ON pixels along scan columns are calculated by an equation of the form

$$\sum_{j=1}^{M} (m_j)^2 \qquad (2)$$

where M is the number of scan columns along the slow scan direction, m is the number of ON pixels in a scan column, and j is a counter for the scan columns along the slow scan direction

From the fast scan and slow scan second order moment data sets, first and second skew angles are calculated **240, 245** The present invention provides two independent skew angle estimates, which are compared and combined **270** in a manner described more fully below. Each skew angle estimate **240, 245** is passed through a validation process **250, 255**, where invalid data sets are discarded **260** and valid data sets are passed on to the compare and combine step **270**, which ultimately yields a resultant skew angle estimate **280**

More particularly, with reference to FIGURE 5 and continuing reference to FIGURE 2, each second order moment data set **500** is subject to a curve

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fit analysis **510** in order to calculate the corresponding skew angle. More particularly, each second order moment data set is fit with an equation of the form.

$$S_\alpha = S_{\alpha max} - k \mid \alpha - \alpha_{max} \mid \tag{3}$$

where $S_{\alpha max}$ is the maximum second order moment value, and α_{max} is the document rotation angle at which $S_{\alpha max}$ occurs. From this fit, the document rotation angle at which the second order moment is substantially a maximum is computed for both the fast scan and slow scan second order moment data sets. In other words, the document rotation angle at which the maximum second order moment occurs is the skew angle estimate.

In order to determine whether the particular second order moment data set is valid, at least one quality factor or q-factor is calculated **520** More particularly, from equation (3), a local quality factor, Q_{loc}, is calculated according to the following equation:

$$Q_{loc} = k = \frac{S_\alpha - S_{\alpha \, max}}{\mid \alpha - \alpha_{\, max} \mid} \tag{4}$$

Q_{loc} is equivalent to the slope of the equation fit to the particular second order moment data set at the local maximum In addition, a global quality factor, Q_{Global}, is calculated according to the following equation

$$Q_{Global} = \frac{(S_{\alpha \, max} - S_{\alpha \, min})}{S_{\alpha \, max}} \tag{5}$$

where $S_{\alpha min}$ is the minimum second order moment value, and α_{min} is the document rotation angle at which $S_{\alpha min}$ occurs It is to be appreciated that Q_{loc} and Q_{Global} are indicators of the strength and integrity of both the fast scan and slow scan second order moment data sets.

The calculated quality factors are used in a number of validation or verification steps described below. The first validation step includes verifying whether each second order moment data set includes a single dominant peak or multiple peaks **530** In one embodiment, a predetermined peak-to-valley threshold is employed to determine the number of dominant peaks present in the second order moment data set However, it is to be appreciated that other conventional methods are

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contemplated. If multiple peaks are present, the data set is determined to be invalid 560. Assuming a single dominant peak, a peak purity test is performed in which it is determined whether the function is strictly decreasing near the dominant peak 540 If a strictly decreasing peak is not present, such as where a side node exists adjacent the dominant peak, the data set is declared to be invalid 560. Conversely, if the single peak is considered to be strictly decreasing, the q-factor or quality factor associated with the peak is compared 550 to a predetermined threshold value If the q-factor does not meet the predetermined threshold, the data set is considered to be invalid and the corresponding skew angle estimate is not used in further processing However, if the q-factor is determined to be greater than the threshold, the data set is considered to be valid 570 and the corresponding skew angle estimate is passed on to the compare and combine step 270

With reference to FIGURE 6 and continuing reference to FIGURE 2, a method of comparing and combining 270 skew angles from valid data sets 600 is illustrated. First, the number of valid data sets is determined 605. If no valid data sets exist, failure is declared 610 and no skew angle is reported. It is to be appreciated that this condition may be present in document images containing extraordinarily large quantities of text and/or numerous varied dominant orientations of text If one valid data set is present, the skew angle corresponding to the valid data set is reported 615 as the resultant skew angle for the particular image.

In the case of two valid data sets, the corresponding q-factors, Q_{Global} and/or Q_{loc}, for each valid data set are compared 620 to one another It is determined whether or not the difference between the q-factors of the two data sets is greater than a predetermined threshold 625 It is to be appreciated that both local and global q-factors may be considered in this determination If the q-factor differences are greater than the predetermined thresholds, the skew angle corresponding to the data set having a higher q-factor is reported 630 as the skew angle for the image This state is characterized as a single dominant data set, that is, a state where one data set has a significantly higher q-factor than the other. If the difference between the respective q-factors is less than the predetermined threshold, the skew angles for both data sets are compared 630. Namely, it is determined whether the difference in skew angles is greater than a predetermined threshold 640 If the skew angle difference is less than the predetermined threshold, the average of the two skew angles is reported 650 as the resultant skew angle for the image. In this case, it is to be appreciated that shear may

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be reported as well, where the shear is equivalent to the angle difference between the two skew angle estimates. However, if the difference between the first and second skew angles is greater than the predetermined threshold, the smaller skew angle estimate is reported **645** It is to be appreciated that reporting the smaller skew angle estimate provides an additional safeguard in an effort to avoid over-correction or over-manipulation of the document image

The invention has been described with reference to the preferred embodiment. Modifications and alterations will occur to others upon a reading and understanding of the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof